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Course Outline

Objectives:

The objectives of this course are to: (1) provide theoretical understanding and practical experience with the most common measurement techniques relevant to hydrology and watershed science; and (2) provide training in collecting, analysing, and presenting scientific data.

The methods that will be used to achieve these objectives include lectures, readings, directed field exercises, lab and homework assignments, field trips, and a final exam. There will be at least one all-day field trip to make discharge and stream channel measurements. These data will be presented and discussed in class the following week.

Text:

There is no single text that covers the material presented in this course, but some of the chapters and appendices in Forest Hydrology by Mingteh Chang cover some aspects of the course as indicated in the course schedule. References for other sections are available online (see particularly the numerous USGS publications at <http://pubs.usgs.gov/twri/>), and additional materials will be provided as handouts.

Projected Grading:

Major lab reports:

Meteorologic measurements: 20-25%

Stream measurements: 20%

Other lab exercises and reports (3): 30-35%

Class participation and attendance: 0-10%

Final exam (take-home): 20-25%

Total: 100%

Office hours:

Monday and Wednesday afternoons 3:00-5:00, Room 203, VFU Guesthouse

Tentative Schedule

Week 1: Course outline, student desires; Traditional measurements (rainfall, temperature relative humidity, wind); Chang Appendix A, pp. 377-388);

Week 2: Wind; evaporation; solar radiation; groundwater levels; Advantages and disadvantages of electronic data collection; tour weather station; rainfall erosivity and RF program if time;

Week 3: Soil moisture; begin monitoring;

Week 4: Surveying, groundwater levels, groundwater gradients (Dunne and Leopold, Chapter 7);

Week 5: Stream classification and channel characteristics (bankfull, slope, bed material);

Week 6: Discharge measurements and rating curves; pebble counts; thalweg profile; (Chang Appendix B, pp. 389-403; Buchanan and Somers, Discharge Measurements at Gaging Stations, <http://pubs.usgs.gov/twri/twri3a8/>; Kennedy, Levels at Streamflow Gaging Stations; <http://pubs.usgs.gov/twri/twri3-A19/html/toc.html>);

Week 7: Field trip to collect discharge and other stream data;

Week 8: Analysis and presentation of field trip data;

Midterm

Week 11: Infiltration and hydraulic conductivity;

Week 12: Sediment measurements in streams: suspended load and bedload (Chang Appendix C, pp. 411-429; Field Methods for Measurement of Fluvial Sediment, <http://pubs.usgs.gov/twri/twri3-c2/>);

Week 13: Water quality 1: site selection, temperature, pH, conductivity, dissolved oxygen (Prof. John Stednick);

Week 14: Water quality 2: turbidity, nitrate, phosphate, hardness, alkalinity, quality assurance/quality control;

(Prof. John Stednick)

Week 15: Erosion processes and measurements: erosion pins and bridges; rainfall simulators; Gerlach troughs and erosion plots; sediment fences; (Chang Chapter 11);

Week 16: Flumes, weirs, and other discharge measurements (dilution techniques); (Chang Appendix B, pp. 403-410); Hydrologic connectivity; Wrap-up.

Final exam:

8 June: 09:15-11:00

Meteorological Instruments: Rain Gauges, Temperature, Relative humidity, Wind, Radiation

RAIN GAUGES

1.1. Principles: Rain gauges should have a sharp edge so and near vertical sides on the inside to minimize rainsplash (drops are either in or out); should have a funnel with a small hole to minimize evaporation losses; sides and funnel should be smooth, hydrophobic material to minimize loss due to wetting of the surfaces conducting water. Standard height in the U.S. is about 75 cm (30 inches). In winter the funnel is typically removed so snow doesn't accumulate on the funnel. Some gauges are heated in winter to melt and measure snow, but this causes some evaporation losses.

Biggest issue is wind, as the turbulence causes undercatch; much more severe for snow. Most common shields to minimize this problem are an Alter (strips of metal hanging around the perimeter) shield and a Nipher shield (like the opening of a tuba); latter will cause overcatch in rain and hail.

Ideal location is in a forest opening to minimize wind effects. Gauge should be located at a distance that is twice the height of the nearest object, which is an angle of 30 degrees from the top of the object (i.e., 60 m from a 30-m tall tree). If necessary, an angle of 45 degrees is acceptable.

Wind effects can be minimized by installing the opening of the gauge at or near ground level, but this makes it harder to service and more susceptible to materials falling into the gauge and possible clogging it, such as leaves.

1.2. Types: standard rain gage gives total. To get the desired accuracy, the water is typically funneled into a smaller tube inside the gauge that is only 10% of the area of the rain gauge. This 10-fold increase allows precipitation to be measured to the nearest 0.1 mm or 0.01 inches.

1.3. Recording rain gauges provide data on rainfall intensity, and these include weighing buckets, tipping buckets, a siphon gauge recording on a chart, or a storage gauge with a pressure transducer.

TEMPERATURE

2.1. Principles. Measurements need to be made in a location that is representative. In most cases this means in a shaded area that is not subject to excessive heating or reflected radiation, such as a grassy area. The thermometer needs to be in a shelter that is painted white and well ventilated so it does not heat up as a result of solar radiation. Traditional wooden shelters have a double roof to minimize heating, and they always open to the north in the northern hemisphere to avoid the sun shining on the thermometers at any time when observations are being made. Electronic thermometers are typically put into a stacked-plate type shelter. All shelters can result in temperatures that are too high under conditions of high radiation loads and no wind; biggest problem is after a fresh snow because of the very high albedo.

2.2. Mechanical measurements all based on principle that higher temperature leads to expansion.

2.2.1. Traditionally liquid-in-glass (=thermometers); usually mercury or alcohol;

Bulb or reservoir and then a narrow tube, so small change in volume leads to a large change in distance; read directly off the scale for regular thermometer;

2.2.2. Maximum thermometer uses mercury, as more viscous; has constriction so that as mercury goes up it can't come down; stays at highest point.

Reset by shaking, but be sure to shake it so that the mercury is forced down into the bulb, not away from it, as once mercury separates it usually is not possible to get it to rejoin!

Very reliable, and is generally the official means to measure maximum temperatures in the U.S., Vietnam, etc.

2.2.3. Minimum thermometer works on different principle; has index, so fluid can go up and around it, but as temperature decreases the index is

pulled down. Given this, measure the UPPER end of the index, not the lower end.

Again this is the standard method worldwide.

2.2.4. Timing of readings: Minimum and maximum give you the minimum and maximum values since the time the thermometer was last reset.

Have to be careful in terms of when you reset them; if you reset the maximum when it is still warm and the next day is colder, it will only give you the temperature you reset it at;

If you reset the minimum thermometer while it is cold and the next day is warmer, again it will stay at the temperature when it was reset; hence you want to reset the maximum thermometer at a time when you know it will get warmer (e.g., shortly after sunrise), and the minimum thermometer at a time when you know it will get colder (e.g., in the afternoon);

2.3. Continuous temperature recordings: To get continuous temperature measurements, need either a mechanical thermometer with a chart or an electronic thermometer.

2.3.1. Mechanical recording thermometers (“thermograph”) also work on principle of expansion, as they typically use two pieces of metal with different expansion coefficients; change in temperature causes differential bending, and this change in angle is converted by a system of rods and levers into a rise and fall on a chart. A mechanical or battery-powered clock is used to drive the chart, and the rate at which the chart moves determines the resolution of the temperature measurements in time; can range from 6 hours to 30 days depending on which combination of gears are used for the clock drive and at the base of the chart; Cost around \$500;

2.3.2. Electronic thermometers are now very reliable and cheap, so they are the dominant means for recording temperatures. These only need a minimal power supply, a clock, a temperature sensor (voltage), and a data logger. Can purchase single-channel temperature loggers for \$20 or less; now use these on refrigerated trucks to check temperatures while shipping

fruit or vegetables across the country or across oceans; Need computer to download the data.

RELATIVE HUMIDITY

3.1. Wet/dry bulb methods compare the difference in temperatures between a thermometer in dry air and a thermometer with a wet bulb (usually a regular thermometer with a small cotton sock on the bulb. The cotton sock is wetted, preferably using deionized water to avoid mineral build up as the water evaporates.

Evaporation from the wet bulb decreases the temperature relative to the dry bulb, and the difference in temperature between the wet and dry bulb thermometers are inversely proportional to the relative humidity (i.e., lower relative humidity leads to a greater temperature difference, while higher relative humidity leads to a smaller temperature difference).

Dry vs. wet bulb differences **decrease** with temperature (i.e., at 50% relative humidity the difference between a dry and wet bulb is greater at 40°C than at 10°C). The difference also is less with **increasing elevation** because the lower air pressure means the atmosphere can hold less water and the evaporation rate is less. These non-linear controls means that one has to use a chart to determine the relative humidity for a given difference in temperatures at a given elevation. A Colorado chart for 1500 m elevation will not work in Vietnam!

Two main methods are: **(1) a sling psychrometer**, where the thermometers are rapidly swung in a circle (or a fan is used to blow air by the wet bulb); and **(2) Stationary method**, where the wet bulb has a continuous water supply. Stationary method may not work as well if no wind, and over time evaporation will lead to mineral deposition on the sock, so it will need to be replaced more often.

Provides instantaneous rather than continuous values.

3.2. Mechanical methods (“hygrograph”) use the principle of expansion and contraction, usually with hairs held at high tension; as the humidity

changes the hairs expand and contract, and again a system of levers transforms this into the vertical movement of a pen on a chart. Cost is about \$500-\$1000. Many instruments combine temperature and relative humidity, so upper part of the chart is temperature and lower part is relative humidity (“hygrothermograph”).

3.3. Electronic instruments now available, and cheaper than a mechanical recorders, but much more than electronic thermometers; electronic hygrographs inherently must have a thermistor to measure temperature since relative humidity is temperature-dependent.

WIND

4.1. Standard method is with a **vertical cup anemometer**. This uses a mechanical or electronic sensor to record each turn. A standard anemometer records turns per unit time, which yields wind speed; a **totalizing anemometer** records total number of turns, which is wind run. Wind speed can be converted into wind run by multiplying the average speed for a given period of time, or integrating shorter-term measurements for the time period of interest. Cost about \$400-1000;

4.2. More recent is the **sonic anemometer**, which measures the effect of wind on the speed of sound. This generates three-dimensional wind speeds, which are useful for measuring the upward flow of CO₂ and water vapor (“eddy covariance”), while cup anemometers only measure lateral winds (two dimensions, but only one integrated value). Cost is in the thousands of dollars.

4.3. Location. Standard measurement height for wind speed is 2 m, but measurements are often made at 30 cm next to an evaporation pan, at 10 m, or above the vegetation canopy. For accurate wind measurements the anemometer needs to be 10 times the height of the nearest vertical element. So in a forest that is 30 m high, the clearing for an should have a radius of 10 x 30 m, or 300 m, which converts to a diameter of 600 m! In the U.S. a totalizing anemometer is almost always placed at a height of about 30 cm adjacent to an evaporation pan, as the evaporation rate is highly dependent on wind run (or wind speed).

4.4. Wind direction is recorded on a 360 degree circle using a wind vane. There are mechanical wind vanes that can record on a chart, but most people now use a wind vane combined with a data logger. The reality is that most people use wind speed, and ignore wind direction.

EVAPORATION

5.1. Standard method is an **evaporation pan**. This is a metal pan that holds water, and one carefully measures the change in water level, usually on a daily basis and sometimes twice a day. U.S. Weather Bureau Class A pans are 120 cm in diameter, 25 cm deep, and filled to 20 cm. Most evaporation pans are above the ground and therefore tend to overestimate evaporation because the metal sides absorb solar radiation. There also is a transfer of sensible heat from the air to the pan because evaporation cools the water in the pan and thus creates a temperature gradient from the air to the pan. To avoid this problem evaporation pans should be floated in a large lake, but this is usually impractical. Sunken pans are more accurate, but are rarely used because they accumulate debris and it is hard to detect a leak should it occur.

Since the pans overestimate evaporation, the pan evaporation value needs to be multiplied by an empirical pan coefficient of about 0.7 to 0.8 to get potential evapotranspiration. The problem is that this coefficient varies seasonally and with location, so there is no single value!

One also has to keep the water level relatively constant, as the evaporation rate will increase as the water becomes shallower due to the proportionally greater radiation load and greater advective heat input per unit of water depth.

An adjacent rain gage is needed to subtract any rainfall from the change in water level. Errors can occur due to birds drinking or bathing in the pan, and they also need to be kept clear of algae and debris

Under night-time freezing conditions the data are not reliable, as some energy needed to melt the ice before evaporation can occur. If the pan

freezes solid, the welds may break and the pan may leak; at about \$3000 for the U.S. Class A pan, this is expensive!

Daily evaporation rates are relatively low (usually 0-10 mm), so the depth measurements need to be very accurate. In the U.S. people raise and lower a point gauge, which has a Vernier scale to the nearest 0.001 inch or 0.001 cm. In Vietnam water is added from a graduated cylinder until the water level reaches a similar point as the U.S. point gauge, and the volume added is divided by the relatively large pan area to get an accurate evaporation rate. Pressure transducers aren't used because they generally do not have a sufficient degree of precision and accuracy.

5.2. Atmometers or evaporimeters use a volumetric change in a narrow glass tube with a saturated cloth or paper at the bottom. The change in water level is recorded daily. Different values will be recorded from an evaporimeter in a shelter versus one in the open because of the much lower wind speeds in the shelter. Big advantage is that these are much cheaper, as they can range from about \$20 to perhaps \$300. Not as widely used as they should be!

RADIATION

6.1. Two main types of radiation are **short-wave** ("solar") and **long-wave** (infrared or thermal). Measurements are generally made by measuring the temperature increase due to radiation hitting a strip of metal that is painted black to absorb radiation. A dome can be used to restrict the type of radiation that is allowed to hit the metal strip.

Measurements of solar radiation can be divided into: (1) **direct**, which would be measured using a long tube pointed directly at the sun ("**pyrheliometer**"); (2) **diffuse**, which comes in at all angles, and (3) reflected from the ground. **Albedo** is the ratio of reflected short-wave from the ground divided by the incoming short-wave.

Long-wave by definition is diffuse, and it is measured as incoming (from the sky) or outgoing (from the ground).

6.2. Pyranometer: measures direct and diffuse short-wave from the sky; glass dome transmits 0.34-2.8 μm , while quartz domes transmit 0.25-4.0 μm ;

6.3. Radiometer measures short and long wave;

6.4. Net radiometer measures the difference between incoming and outgoing. Values are positive during the day and negative at night.

6.5. Pyrgeometer: measures long-wave.

6.6. Duration of direct solar radiation. Another, cruder method of measuring solar radiation is with a spherical ball. This concentrates the solar radiation onto a strip of special paper, and the presence of direct solar radiation is indicated by burning a narrow strip as a result of the concentrated solar radiation. The thickness of the burned strip indicates the magnitude of solar radiation, but it is difficult to convert this into an amount. Hence this is most useful for indicating the duration of sunshine (direct solar radiation) rather than the amount.

PPT

Title	Download
Introduction	<u>Download</u>
Measuring Water Levels	<u>Download</u>
Stream and discharge measurements	<u>Download</u>
Stream classification	<u>Download</u>
Electronic data	<u>Download</u>

Lab No. 3: Stream and Channel Measurements

Field Work (21 March)

The class will be broken into groups. You must work with different people than you worked with for the weather station measurements. We will visit two sites, with a set of tasks to be done at each site. Each group is responsible for the following:

Site 1 (below a small dam):

(1) Locate and survey one cross-section; identify bankfull stage IF that can be identified in the stream section we are studying. Be sure to measure the left and right edge of water (LEW and REW, respectively), and remember the hydrologist always faces downstream.

(2) Measure discharge at your designated cross-section. You should try to have no more than 10% of the flow in any one section. Since we only have one current meter, just make one measurement in each section for 10 seconds at 0.6 of the depth.

(3) At the deepest point in the stream ("thalweg"): (a) measure the velocity with a current meter at 0.2, 0.4, 0.6, and 0.8 times the depth; do this for a minimum of 40 seconds and use the rating table provided to you; (b) measure the velocity using $v = (2gh)^{0.5}$, where h is the rise in water level against some obstruction, such as the stadia rod; and (c) measure the velocity using a float over a distance of around 5 m.

(4) Measure the water surface slope along a short reach centered on your cross-section using a clinometer.

(5) Estimate a value for Manning's " n " for the area immediately around your cross-section. Guidance for this should come from the tabulated values in the handout (Chow, 1959).

(6) Do a Wolman pebble count (minimum of 100 pebbles) along your cross-section. Samples should be systematically spaced at a distance that is roughly equal to the second or third largest particle in your cross-section. Note that you will need several transects across the stream in order to obtain the necessary sample size (each additional transect should be about one meter upstream of the previous count). Sampling transects should extend from bankfull to bankfull. (7) Collect the information to classify the stream in the vicinity of your cross-section according to: (i) Rosgen (1994) and (ii) Montgomery and Buffington (1993, 1997).

Site 2 (more natural reach):

(1) Locate and do a rough survey (maximum of 20 points) of one cross-section. Locate the cross-section in a location that would be good for measuring discharge. Be sure to identify current water level and bankfull in your survey.

(2) Measure the water surface slope along a short reach centered on your cross-section using a clinometer.

(3) Estimate a value for Manning's "n" for the area immediately around your cross-section. Guidance for this should come from the tabulated values in the handout (Chow, 1959).

(4) Collect the information to classify the stream in the vicinity of your cross-section according to: (i) Rosgen (1994) and (ii) Montgomery and Buffington (1993, 1997).

(5) Each individual should make a field sketch (plan view) of the channel reach under study. This sketch should include the banks and an indication of the adjacent topography and vegetation. Be sure to include, along with other important features: (i) the approximate location and size of the major habitat units within the study reach; and (ii) the approximate location of each cross-section. To facilitate the drawing of the sketch maps, each group should leave their string up until the entire class has completed all portions of this exercise.

Data to be Turned in by 1500 on 25 March

Each team must slide the following data under Lee's door in the VFU guesthouse (Room 203) by 1500 on Wednesday, 25 March so that it can be copied and distributed in class. This means the data must be clearly labeled and legible, and each sheet should include the names of your team and your cross-section number. Failure to submit data on time, or to submit it in a form that requires additional verbal explanation, will result in a substantial penalty for all team members.

Site 1:

(1) A plot of your cross-section that includes: (a) the water level at the time of your survey; (b) the estimated bankfull stage if that can be identified (we will determine this in the field); (c) the measured discharge in cms (cubic meters per second); and (d) the date, time, and type of current meter used to measure discharge.

(2) The pebble count should be plotted on A4 paper using a semi-log scale (i.e., diameter in millimeters on a log scale on the x axis and percent finer than with an arithmetic scale of 0 to 100 percent on the y axis). It goes without saying that the graph should be properly labelled (names, cross-section number, axes, etc.). Give the size of the D16, D50, and D84 particles to the nearest millimeter, and use dotted lines to show how you obtained these values. Also indicate whether you used a gravelometer or a ruler to measure the particle size.

Site 2:

(1) A plot of your cross-section. This should show: (a) the water level at the time of your survey; (b) the estimated bankfull stage on each side of your cross-section; (c) the current water level; and (d) the difference in vertical elevation between the current water level and your estimate of bankfull for each side of the stream.

Data to be Compiled, Calculated, and Brought to Class on 28 March

The following data should be compiled and calculated prior to the beginning of class on 28 March. In this class period we will review how the data should be presented, compare the results from each group, and discuss the reasons for any observed differences. For this process to work, you must have all of the following information compiled or calculated BEFORE coming to class.

Site 1:

- (1) Number of verticals used for your discharge measurement and the percent of flow in each vertical;
- (2) Measured velocities at the deepest point in the stream using each of the methods listed under task #3 in the section on field data collection;
- (3) Calculated discharge using Manning's formula;
- (4) Back-calculated Manning's "n" (rearrange Manning's equation to solve for n, and plug in your measured discharge and cross-section data);
- (5) Stream classification according to both Rosgen and Montgomery-Buffington, and the values for each of the criteria in the Rosgen classification at each site to the extent they can be identified (i.e., bankfull width; bankfull depth; width/depth ratio; entrenchment ratio; etc.);
- (6) D16, D50, and D84 for your cross-section;
- (7) Stream gradient as measured with the clinometer.

Site 2:

- (1) Estimated vertical difference between bankfull and current water level for each side of the stream;
- (2) Estimated Manning's "n" and calculated discharge using Manning's formula for: (a) current water level; and (b) bankfull discharge;
- (3) Stream classification according to both Rosgen and Montgomery-Buffington, and the values for each of the criteria in the Rosgen classification at each site to the extent they can be identified (i.e., bankfull width; bankfull depth; width/depth ratio; entrenchment ratio; etc.);
- (4) Stream gradient as measured with the clinometer.

Reports (due October 25)

For this lab you will submit both a team and an individual report, and these are described below. You should read and reference the appropriate sections of the reader, as some of the questions will require a deeper understanding of the procedures used to collect your data and the resulting uncertainties.

With regard to the team report, it is important that your answers be formulated as a group, as that is the only way that each team member can become familiar with all the issues and topics associated with this lab. If you already have considerable experience in this type of work, please don't take over or attempt to dominate your group; most learning takes place as people grapple with a problem, and the least experienced gain the most from helping to develop the answers to each of the following questions.

Group Report

Site 1

1. (a) Make a table comparing the velocities measured at the deepest point in the stream using the following techniques: (1) velocity at 0.6 times the depth; (2) mean velocity using 0.2 and 0.8 times the depth; (3) mean velocity using all depths; (4) float times 0.85; and (5) the velocity head

method. (b) Comment on the relative reliability of each of the five techniques used to measure velocity, and then indicate which technique(s) would you recommend, and which are unreliable. Be sure to justify your answers.

2. Provide a final plot of your surveyed cross-section.

3. (a) What was your measured discharge? (b) How did your value compare to the other discharge measurements? (c) Using the information presented in class and the reader, list—in order of importance—the most likely reasons for the variability in the measured discharge values among groups. Briefly explain and justify your list.

4. (a) Provide a final plot of your particle-size distribution. (b) From this plot or the raw data list your D₁₆, D₅₀, and D₈₄ values. (c) How do your values compare to the values obtained at the other cross-sections? (d) Using the material in the reader (e.g., Wolman, 1954; Platts et al., 1983) and presented in class, do you think that your data accurately represent the true distribution of particle sizes on the channel bottom at your cross-section? Briefly explain why or why not.

5. (a) What was your estimated value for Manning's n ? (b) Show your calculations to estimate the discharge using Manning's equation. (c) Compare your calculated discharge to the measured discharge. (d) Rearrange and solve Manning's equation for n using your measured discharge (i.e., what value would Manning's n have to be for the calculated discharge to equal the measured discharge?). (d) In cases where we do not have a gaging station, the discharge associated with extreme events is typically estimated using Manning's equation. Comment on the usefulness and accuracy of Manning's equation to estimate large flow events.

7. (a) What is your channel classification according to Rosgen (1994)? (b) What is your channel classification according to Montgomery and Buffington (1993, 1997)?

Site 2:

1. Provide a final plot of your surveyed cross-section.

2. (a) What was your estimated value for Manning's n ? (b) Show your calculations to estimate the discharge using Manning's equation.

7. (a) What is your channel classification according to Rosgen (1994)? (b) What is your channel classification according to Montgomery and Buffington (1993, 1997)?

Individual Reports

1. For site 2, comment on your ability to distinguish bankfull, and the likely accuracy of the bankfull values estimated by your group.

2. Comment on the current condition of the stream. Is it aggrading (sediment being deposited) or incising? Are the banks actively eroding? Does the stream look healthy to you? Why or why not? (I realize this is not an easy question, but please try. You should write somewhere between one paragraph and about one page.)

3. Attach your individual sketch map for site 2. Note that the two main purposes of a sketch map are: (1) to allow you or another observer to find the reach and locations where specific data were collected; and (2) document the current features of interest so that your or another observer could come back at a later date and determine whether there have been significant changes in the channel or adjacent riparian zones.